Atmospheric behavior, deposition, and budget of radioactive materials from the Fukushima Daiichi nuclear power plant in March 2011

Morino, Y., T. Ohara, and M. Nishizawa (National Institute for Environmental Studies, Japan, morino.yu@nies.go.jp)

—Introduction—

✓A nuclear accident at the Fukushima Daiichi nuclear power plant (FDNPP) accompanied the great Tohoku earthquake and tsunami on March 11 2011, and as a result, enormous amounts of radionuclides were emitted into the atmosphere and the ocean.
✓Because radioactive contamination of soil and land water is caused mostly by atmospheric deposition, understanding the spatial and temporal distributions of radioactive materials in the atmosphere and their deposition over land masses and oceans is important.
✓Numerical simulations have played an important role in furthering the understanding of spatiotemporal variations of radioactive materials in the atmosphere.
✓In this study, we simulated transport and deposition processes of I-131 and Cs-137 using a chemical transport model, CMAQ (Byun and Schere, 2006).

—Methodology—

Table 1 Model settings

Meteorological model	WRF v3.1 (JMA, MSM)
Chemical transport model	CMAQ v4.6
Domain settings	Figure 1 (237 x 237 x 34 grids)
horizontal resolution	3 km
Target species	I-131 and Cs-137 (parameters are given in Table 3)
Emissions	Updated version of Chino et al. (2011): (Nagai, personal communication, 2011, Figure 5).
Period	10-30 March 2011
Configuration in CMAQ	✓Tracer calculation (TRC). ✓No chemical/aerosol processes ✓Programs in Table 2 are changed: ✓Process Analysis was used for the budget analysis.
# Emission data and Horizaontal resolution are updated from Morino et al. (GRL, 2011).	

Table 2 Programs of CMAQ updated for the radionuclides simulation.

1. Radioactive decay	driver.F
2. (Tracer calculation) Change of unit from mixing ratio to activity concentration	couple.F, AERO_EMIS.F, conv_cgrid.F, vdiffacm2.F, aq_map.F, aqchem.F, cldproc_acm.F, scavwdep.F + include files
3. Calculation of dry deposition	aero_depv.F

Table 3 Parameters of I-131 and Cs-137 used in this simulation.

	I-131	Cs-137
Radioactive decay	8.02 days	—
Gas-particle ratio	0.8:0.2	All particles
Particulate diameters	1 μm	
Dry deposition	Same as "SO_2" for gas	—

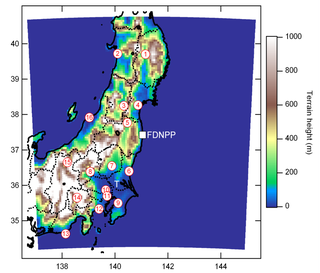

Figure 1. Model domain used in the CMAQ simulation. Numbered prefectures: 1, Iwate; 2, Akita; 3, Yamagata; 4, Miyagi; 5, Fukushima; 6, Ibaraki; 7, Tochigi; 8, Gunma; 9, Chiba; 10, Saitama; 11, Tokyo; 12, Kanagawa; 13, Shizuoka; 14, Yamanashi; 15, Nagano; 16, Niigata. The white square indicates the site of the Fukushima Daiichi nuclear power plant (FDNPP); the white "T" indicates the Tsukuba site.

—Conclusions—

✓Simulation of the spatial and temporal variations of I-131 and Cs-137 around Fukushima Daiichi nuclear power plant (700 × 700 km^2) during March 11–30, 2011 by using a CTM, CMAQ.
✓The model roughly reproduced the observed temporal and spatial variations of deposition rates of I-131 and Cs-137 over 15 prefectures in Japan (60–400 km from the FDNPP), although there are some discrepancies between the model and observations, considerably due to uncertainties in the problems in the treatment of emission, transport, and deposition processes in the model.
✓Budget analysis indicated that approximately 12% of I-131 and 31% of Cs-137 deposited over lands in Japan, and the rest were deposited to the ocean or transported outside of the model domain.
✓Most of radioactive materials emitted from FDNPP were deposited or transported outside of the model region within a few days, and not stay in the atmosphere in the model domain.

—Results—

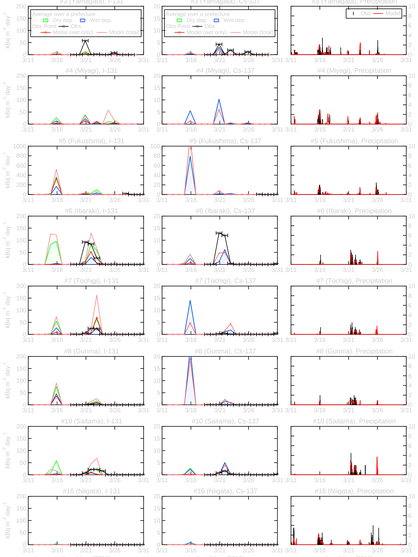

Figure 2. Observed and simulated deposition rates of I-131 (left) and Cs-137 (center) and precipitation rates (right) at selected measurement sites shown in Figure 1. Simulated dry and wet deposition rates averaged over each prefecture are indicated by green and blue hatching, respectively.

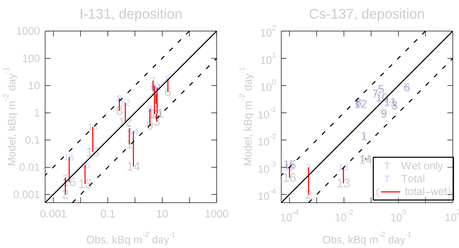

Figure 3. Observed and simulated deposition rates of I-131 (left) and Cs-137 (right) at measurement sites shown in Figure 1 averaged over the period from 18 to 30 March (i.e., N=13 for each measurement site).

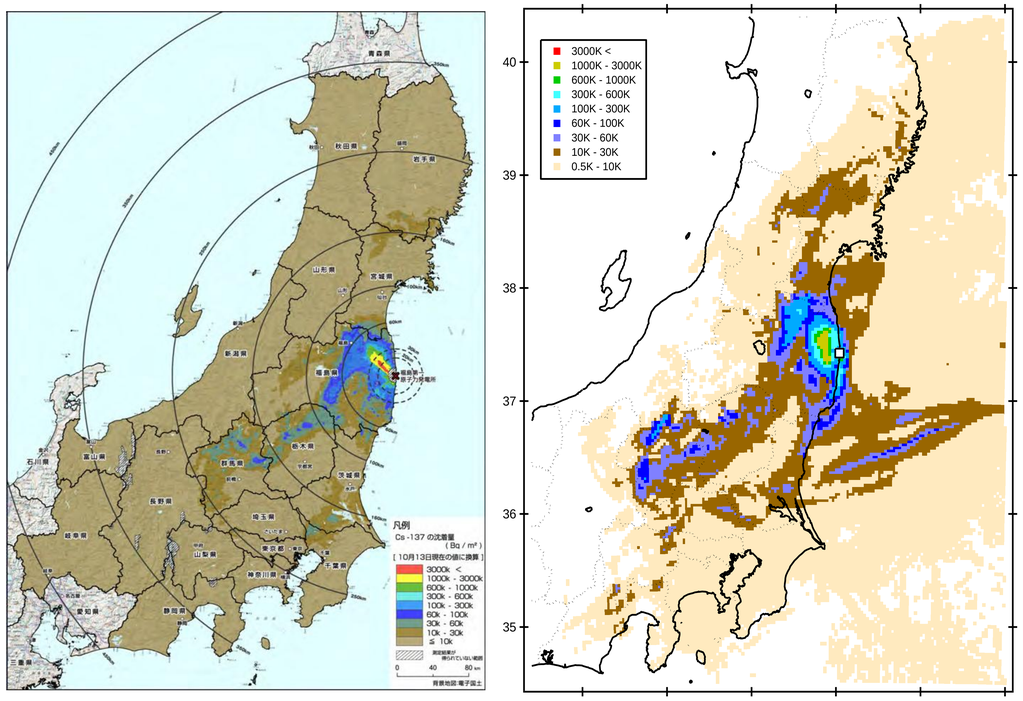

Figure 4. Observed (left) and predicted (right) distributions of accumulated deposition rates of Cs-137. Observed data are estimated using aircraft measurement data (Ministry of Education, Culture, Sports, Science, and Technology, 2011). Simulated data are averaged over 11–29 March 2011.

✓Temporal variations and spatial distributions of Cs-137 deposition rates are reproduced by the model (roughly within one order).
✓Deposition of I-131 and Cs-137 over land in Japan predominantly occurred during 15-16 and 20-23 March 2011.
✓Deposition of Cs-137 were dominated by wet deposition and showed inhomogeneous distribution.

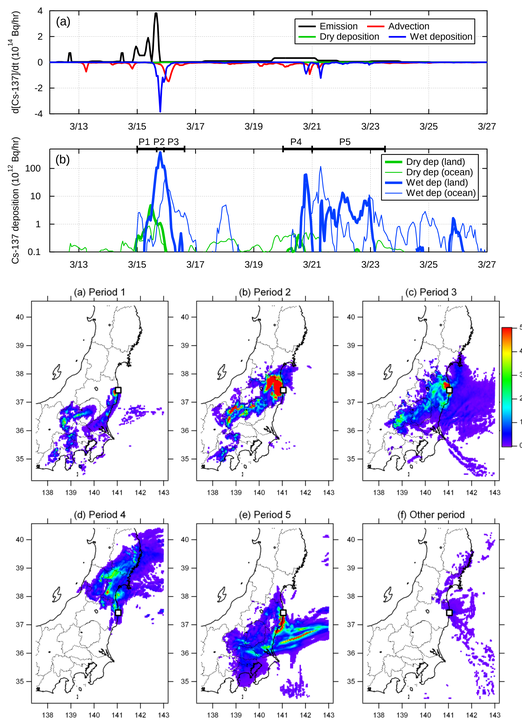

Figure 5. (Upper) Budget analysis of Cs-137 in the model domain. (Lower) Simulated spatial distributions of Cs-137 in Periods 1–5 and other period during 12–29 March 2011.

Table 1 Simulated budget of I-131 and Cs-137 (Bq) in the model domain during 11-30 March 2011.

		I-131	(contr.)	Cs-137	(contr.)
Emission		1.13×10^{17}	100.00%	6.08×10^{15}	100.00%
Advection + diffusion		-7.00×10^{16}	(−62.7%)	-3.26×10^{15}	(−53.5%)
Dry deposition		-2.91×10^{16}	(−25.8%)	-9.09×10^{13}	(−1.5%)
Wet deposition		-8.63×10^{15}	(−7.7%)	-2.65×10^{15}	(−43.6%)
Dry deposition					
	land	-8.92×10^{15}	(−7.9%)	-3.78×10^{13}	(−0.6%)
	ocean	-2.01×10^{16}	(−17.9%)	-5.32×10^{13}	(−0.9%)
Wet deposition					
	land	-4.83×10^{15}	(−4.3%)	-1.84×10^{15}	(−30.2%)
	ocean	-3.80×10^{15}	(−3.4%)	-8.18×10^{14}	(−13.5%)

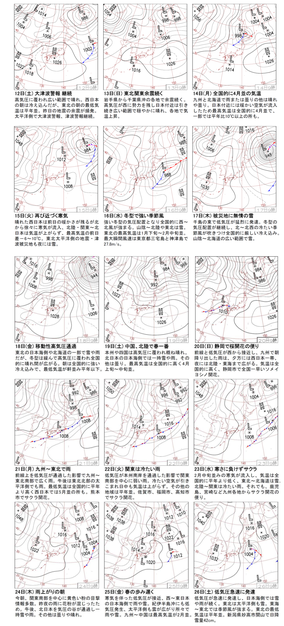

Figure 6. Weather charts at 0900 local time during 12–26 March 2011.

✓Deposition of Cs-137 predominantly occurred during 15–16 and 20–23 March, when the transient cyclone passed over Japan.
✓Cesium-137 deposited in the northwestern direction of the plant in the afternoon of 15 March, over north-west of Kanto Area during 15-16 March, east of Kanto Area during 21-23 March, and north of Miyagi during 20 March.
✓Approximately 12% of I-131 and 31% of Cs-137 deposited over lands in Japan